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Diversification Strategies and Adaptation Deficit: Evidence from Rural Communities in Niger

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SUMMARY

The paper provides fresh empirical evidence on the adaptation process in Niger rural communities using original longitudinal socio-economic panel data merged with granular geo-referenced climatic information. We identify the main drivers and impacts of crop and labor diversification which constitute two livelihood strategies on moderating the adaptation deficit. In doing so, we account for the interdependence between the two diversification practices and potential reverse causality between welfare outcomes and diversification behavior. Moreover, we condition the impacts of diversification on different sections of the welfare distribution to capture potential non-linear effects. Our results reveal that the diversification has positive and significant welfare impacts when most vulnerable households rely on it as an adaptation strategy to mid-run climate variability and as a coping strategy to short-run market shocks. At the same time, our results find lower but still positive impacts for well-endowed households that are likely to diversify their activity portfolio. Given the very limited presence of policy support, we conclude that the rural Nigerien communities are characterized by a large and autonomous adaptation response which constitutes a key leverage mechanism for policy makers. We thus suggest government interventions aimed at supporting the most important diversification drivers, but also aimed at straightening some channels, such as network infrastructures or the promotion of local crop varieties, which may have a greater potential in triggering diversification.

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1. Introduction

There is overwhelming consensus that global climate change is altering the variability of rainfall, temperature, and other climatic parameters and that these modifications will probably lead to an increase in the incidence of environmental disasters (IPCC, 2012; Kahn, 2005; Parry, Rosenzweig, Iglesias, Livermore, & Fischer, 2004; Toya & Skidmore, 2007; Olsson et al., 2014 among others). Although it has been estimated that up to 40% of the world's land surface will develop novel climates (Williams, Jackson, & Kutzbach, 2007), "climate change, variability, and extreme events [will] make the poor even poorer" (Noble *et al.*, 2014). The hypothesis that the consequences of extreme events and climate anomalies will affect poorer countries more than richer ones is also confirmed by the World Bank (2013). In addition to exogenous factors, such as geographical position and concentration of populations in hazard zones, the reason lies in the so-called 'adaptation deficit' (Barr, Fankhauser, & Hamilton, 2010; Brooks & Adger, 2004; Tol & Yohe, 2007; Yohe & Tol, 2002). Adaptation deficit entails a situation in which a country experiences a lack of institutional, economic, and technological means to facilitate the adaptation process. The literature identifies a set of additional individual factors that can raise the vulnerability level such as gender, age, health, social status, ethnicity, and class (Adger *et al.*, 2009; Smit *et al.*, 2001). It is thus clear that communities living in the poorest countries whose livelihoods are directly climate sensitive show a weaker resilience capacity to climate change impacts and a reduced ability to deal with adaptation measures (Fankhauser & McDermott, 2014).

According to Pearce *et al.* (1996) and McCarthy (2001), Sub-Saharan Africa (SSA) represents a major source of concern for future climate change impacts as a result of its strong dependence on subsistence agriculture in marginal and degraded rainfed lands (Cooper *et al.*, 2008; Mendelsohn & Dinar, 2009; Seo, Mendelsohn, Dinar, Hassan, & Kurukulasuriya, 2009). These areas are affected by

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weather changes, short-term anomalies, and long-run climate variability which can severely reduce yields, undermining the availability of both food and feed (Calzadilla, Zhu, Rehdanz, Tol, & Ringler, 2013; Challinor, Simelton, Fraser, Hemming, & Collins, 2010) and increasing vulnerability for sectors of the population (Morton, 2007). In this setting, adaptation processes against extreme climate events emerge as effective strategies to be undertaken by the most exposed communities (Adger, Huq, Brown, Conway, & Hulme, 2003), both at the national and local level (Thornton, Jones, Alagarswamy, Andresen, & Herrero, 2010). In particular, local processes have given rise to a flourishing empirical literature aimed at measuring the impact of adaptation in developing countries exposed to climate risks (for a recent review, see Asfaw *et al.*, 2015). However, a growing concern for rapidly expanding population dynamics and the increasing risks due to climate variability call for additional evidence in order to provide information on the effectiveness of livelihood options available to the most vulnerable communities and correctly support policy makers.

Since climate variability interacts with other non-climatic factors such as lack of natural and economic assets, most vulnerable communities have even lower livelihood capacities. This interaction results in context-specific conditions of marginalization, multidimensional vulnerability, and differential impacts. Accordingly, the status of vulnerability of subsistence farmers is moreover exacerbated by market shocks which translate into high agricultural input and food prices, thereby undermining the food security of already stressed households (HHs) (Morduch, 1995; Timmer, 2000). Vulnerable communities living in rural areas characterized by low income, a minimum educational level, a lack of technical knowledge as well as insufficient policy responses and safety nets, are those affected the most by the consequences of these complex interactions. Thus, the degree to which households increase their resilience to continuous changes is dependent on access to strategic assets, which also identifies their capacity to cope *ex-post* or adapt their livelihood in the long term (Eriksen, Brown, & Kelly, 2005; Folke *et al.*, 2002). In this context, whereas adaptation can be seen as a structural adjustment to actual or expected long-term variation, coping is a process through which the HH moderates, mainly with reversible and purely reactive actions, the potential impacts of perceived random climatic anomalies (Folke *et al.*, 2002; Pelling, 2010).

Among the different contributions that have analyzed the impact of climate change on adaptation strategies in SSA countries, Niger—one of the most vulnerable countries—has surprisingly received very little attention. Niger constitutes an interesting case for analysis since it represents a critical area for climate variation and, at the same time, a highly vulnerable country in terms of potential capabilities to face climatic events and economic shocks (Pachauri, Meyer, Plattner, & Stocker, 2015). Different factors can potentially make Nigerien communities particularly reluctant to implement effective adaptation measures, including a high presence of extensive rain-fed subsistence agriculture, very low education rates and a lack of policy supports. These elements constitute tangible and intangible barriers to adopting adaptation practices which may result in adaptation lock-in and leads to "wait and see" or reactive approaches, low cognitive learning, misperception, and insufficient awareness of climate risks with inefficient adaptation response to extreme events (Baird, Plummer, Haug, & Huitema, 2014; Le Dang, Elton, Nuberg, & Bruwer, 2014). In some cases, these barriers can also lead to competing behaviors of indigenous traditions versus modern and more effective adaptation strategies (Baird & Gray, 2014).

In light of this, our contribution to the existing literature is manifold. Given the limited evidence on the use and impact of diversification practices from the Sahel area at large, and from Niger in particular, which is largely attributed to the lack of reliable data from this country, our analysis adds great value in filling this gap in the existing literature. We employ a large longitudinal national representative HH level survey with rich socio-economic information, merged with detailed geo-referenced climatic information to identify the farmers' diversification strategies and their impacts on welfare. To the best of our knowledge, there are no studies that have looked at this issue in a rigorous manner in Niger by employing a panel dataset. Moreover, we explicitly consider the possibility that farmers rely on a mix of diversification options using a seemingly unrelated regression (SUR) model which accounts for potential interdependence between different diversification practices. The impact of diversification practices is estimated through two welfare indicators using instrumental variable techniques and is conditioned to different levels of the welfare distribution by means of quantile regression.

The remainder of the paper is as follows. Section 2 describes the theoretical background and presents the conceptual framework. Section 3 introduces the interesting case of Niger. The data are presented in Section 4 together to some preliminary analysis, while the empirical methodology is provided in Section 5. Section 6 includes the model results and Section 7 concludes with some policy implications and limitations of the study. The final Appendix provides further research material.

2. Conceptual framework

Several studies have investigated the effect of coping and adaptation strategies in stabilizing and adjusting the livelihoods of rural communities when facing the adverse effect of climate risk. The literature has analyzed the impact of migration, climate smart agricultural practices, and modern technologies adoption, safety-net programs, micro-credit, and diversification (Bazzi, Gaduh, Rothenberg, & Wong, 2016; Fankhauser, Smith, & Tol, 1999; Fenton, Paavola, & Tallontire, 2017; Howden *et al.*, 2007; Kinsey, Burger, & Gunning, 1998; McLeman & Smit, 2006). In this context, diversification emerges as an effective strategy for vulnerable HHs to manage adverse impacts on income and food security caused by extreme climatic events, uncertain agricultural production but also unexpected market shocks (Asmah, 2011; Barrett, Reardon, & Webb, 2001; Di Falco, Adinolfi, Bozzola, & Capitanio, 2014; Di Falco & Perrings, 2005; Di Falco, Veronesi, & Yesuf, 2011; Heltberg, Oviedo, & Talukdar, 2015; Morduch, 1995). However, the literature has also stressed as poorly endowed HHs can be locked-in in a diversified, but low-returns, set of activities (Lohmann & Liefner, 2009; Reardon, Taylor, Stamoulis, Lanjouw, & Balisacan, 2000).

SSA is expected to be one of the most vulnerable areas in the next decades for manifold reasons. First, in the SSA region, agriculture represents the main sector in terms of employment, with about 98% of agriculture exploiting marginal rain-fed lands (Wani S. P. & Rockstrom J., 2009). Stagnant agricultural yields and high population growth have led to a fall in per-capita food availability since the 1970s, although this was reversed with improved performance during 2000–10 (Nin-Pratt, Johnson, & Yu, 2012). However, recent increases in global food prices and climate variability have aggravated food insecurity, with consequent risks of malnutrition (INS-Niger (Institut National de la Statistique), 2015). Moreover, SSA is expected to be strongly affected by climate changes since future projections based on observed trends indicate that temperatures could rise faster than the global average increase during the 21st century (James & Washington, 2013; Joshi, Hawkins, Sutton, Lowe, & Frame, 2011; Sanderson, Hemming, & Betts, 2011). Although most areas in the African continent lack sufficient observational data to draw conclusions about trends in annual precipitation, this is also expected to change. In

particular, rains in SSA experienced an overall reduction during the 20th century, especially in the Sahel region,[1] and such a trend is expected to perpetrate in coming years (Niang *et al.*, 2014). Recent evidence also suggests that climate change will affect both biotic (pest, pathogens) and abiotic (solar radiation, water, temperature) factors in crop systems, with an increasing threat to the crop sustainability, production and food security of subsistence based rural HHs (Niang *et al.*, 2014).

Within this context, it is worth investigating the impact of diversification on vulnerable Nigerien farmers' welfare following the Sustainable Rural Livelihoods (SRL) conceptual framework (Bebbington, 1999; Ellis, 2000; Niehof, 2004; Martin & Lorenzen, 2016; Nguyen, Nguyen, Lippe, & Grote, 2017). Accordingly, a rural HH can be seen as a decision-unit agent who reacts to potential climatic anomalies or market shocks by diversifying its portfolio of income source to be insured, *ex-ante,* against risks, and/or *ex-post* for coping with negative impacts on welfare. While *ex-ante* diversification can be a planned and deliberate strategy of a risk adverse farmer in response to an expected potential change, *ex-post* diversification is a feedback action to an unanticipated shock that shrinks the HHs' welfare (Ellis, 2000; Kelly & Adger, 2000; Eriksen *et al.*, 2005). The timing of such a response also depends on the HH's characteristics determining the perception and awareness of involuntary anomalies (Barrett *et al.*, 2001; Reardon, Berdegué, Barrett, & Stamoulis, 2006) whereas the extent to which they expect climatic or market variability is related to past long, mid-, or short-term experience with such shocks (Adger *et al.*, 2009).

The degree to which farmers diversify is, thus, driven by their degree of risk aversion and vulnerability status that is, nevertheless, linked to the endowment of assets to which an HH i has access at time t (Carney, 1998). These can be seen as a vector of strategic capitals K for which

$$K_{it} = \{K^N_{it}, K^P_{it}, K^H_{it}, K^F_{it}, K^S_{it}\}. \quad (1)$$

Here K^N_{it} stands for natural capital (e.g., cultivated land), K^P_{it} represents physical agricultural assets (e.g., tractors, transportation), K^H_{it} is human capital (e.g., education, gender), whereas K^F_{it} and K^S_{it} are vectors of financial (e.g., credit access) and social assets (e.g., networks), respectively (Ellis, 2000; Scoones, 1998). These assets contribute to defining the livelihood options available to farmers and are correlated in explaining both the crop and labor diversification (Cinner & Bodin, 2010; Nguyen *et al.*, 2017). For instance, a land endowed farmer, with limited access to agricultural inputs or to credit, could rely on crop diversity as a substitute input for chemical fertilizers (Bellon, 2004; Jarvis *et al.*, 2008). Although this strategy can protect farmers from potential inputs and output price fluctuations and guarantee dietary diversity, it is likely that farmers pay a premium to risk in terms of average productivity (Chavas & Di Falco, 2012; Di Falco & Chavas, 2009). The farmer can thus push themselves to find alternative sources of income which, on the other hand, may be achievable only with access to adequate levels of human or social capital (Anderson, Locker, & Nugent, 2002). In the case of sub-Saharan regions, the evidence of these types of mechanisms is confirmed by the increasing income shares of non-farm activities in rural HHs as a response to low returns in traditional core activities (Barrett *et al.*, 2001; Block & Webb, 2001; Davis *et al.*, 2010; Ellis, 2009).

[1] The large number of droughts in the Sahel during the 1970s and 1980s is well documented (Biasutti & Giannini, 2006; Biasutti, Held, Sobel, & Giannini, 2008; Greene, Giannini, & Zebiak, 2009). The recovery of rains during the last 20 years of the century may be due to natural variability (Mohino, Janicot, & Bader, 2011) or a forced response to increased greenhouse gases (Haarsma, Selten, Weber, & Kliphuis, 2005) or reduced aerosols (Ackerley *et al.*, 2011).

The background of the SRL can be easily adapted to a simplified non-separable farm HH model in which on-farm crop diversification and off-farm labor supply are simultaneously determined and affected by the same set of exogenous expected or unexpected shocks and asset endowments (De Janvry, Fafchamps, & Sadoulet, 1991; Wouterse & Taylor, 2008). The HH welfare W, at any time t and in a risky environment subject to shocks S, could be represented as a random variable

$$W_t = f[D_t(S_{t-\tau}, K_t); Z_t] \quad (2)$$

in which the vector of crop and labor diversification D is a livelihood strategy that HHs adopt to be insured against, or cope with, S experienced over a time span defined by τ and in accordance with K and unobserved factors Z. While we may expect to observe

$$\frac{\partial W}{\partial S} < 0 \quad (3)$$

$$\frac{\partial W}{\partial D}(S^0) < \frac{\partial W}{\partial D}(S^1) \quad (4)$$

for $S^1 > S^0$, the impact of K on both crop and labor diversification, and consequently on welfare, is multidirectional. The latter depends on the allocation of such endowments between different on-farm and off-farm activities as exemplified above. Moreover, it is also likely that this impact is non-linear as is the case for proactive well-endowed farmers who diversify labor as a result of greater financial and social opportunities (Cinner & Bodin, 2010; Martin & Lorenzen, 2016).

Although several empirical contributions point to a large consensus on the fact that HHs living close to densely populated areas are more prone to adopt labor diversification strategies (Barrett *et al.*, 2001; Canagarajah, Newman, & Bhattamishra, 2001; Lanjouw, Quizon & Sparrow, 2001; Asmah, 2011), rural HHs, which represent the most vulnerable sub-groups of population, are only marginally investigated and the determinants pushing them to combine crop and labor diversification have been so far neglected. With specific regard to Niger, considering the scarce empirical evidence existing in the literature and the high vulnerability of the country, there is room to investigate the determinants of diversification practices and their impacts on rural communities by focusing on the role of climate and market anomalies that may affect HH diversification decisions.

3. Niger as a case study

Niger is a SSA country, divided into eight main administrative regions.[2] Four-fifths of the Nigerien northern territory are occupied by desert whereas the southern area is savannah, suitable for livestock and limited agriculture. The social pattern is characterized by a variety of ethnicities, with a prevalence of Haoussa, Djerma Sonrai and Tuareg. At the political level, Niger is facing increasing security concerns on its borders from various external threats including insecurity in Libya, spillover from the conflict in Mali, and violent extremism in north-eastern Nigeria (CIA, 2014). Demographic dynamics are governed by one of the highest birth rates in the world (4.6%), with a median age of population of 15.1 years (CIA, 2014). At the present pace, Niger's population is expected to double in the next fifteen years. Considering that Niger is a landlocked country that depends on agricultural, agro-pastoral, and pastoral livelihoods (agriculture and livestock production represents 45% of Niger's GDP, involving more than 80% of the population (FAO, 2015), the rapid population expansion is likely to affect the natural resources

[2] Ahadez, Diffa, Dosso, Maradi, Tahoua, Tillaberi, Zinder, Urban Community of Niamey.

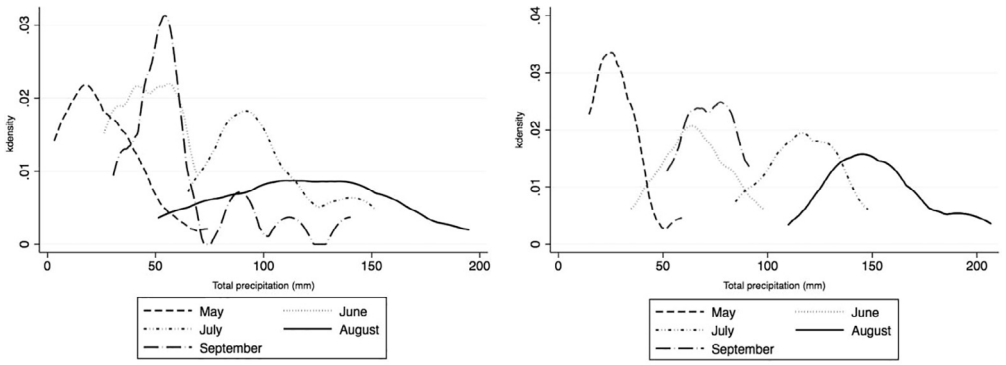

Figure 1. Density functions on average precipitations in growing season. Comparison between 1983–2000 and 2001–2014. *Source:* authors' elaborations based on ARC2 database.

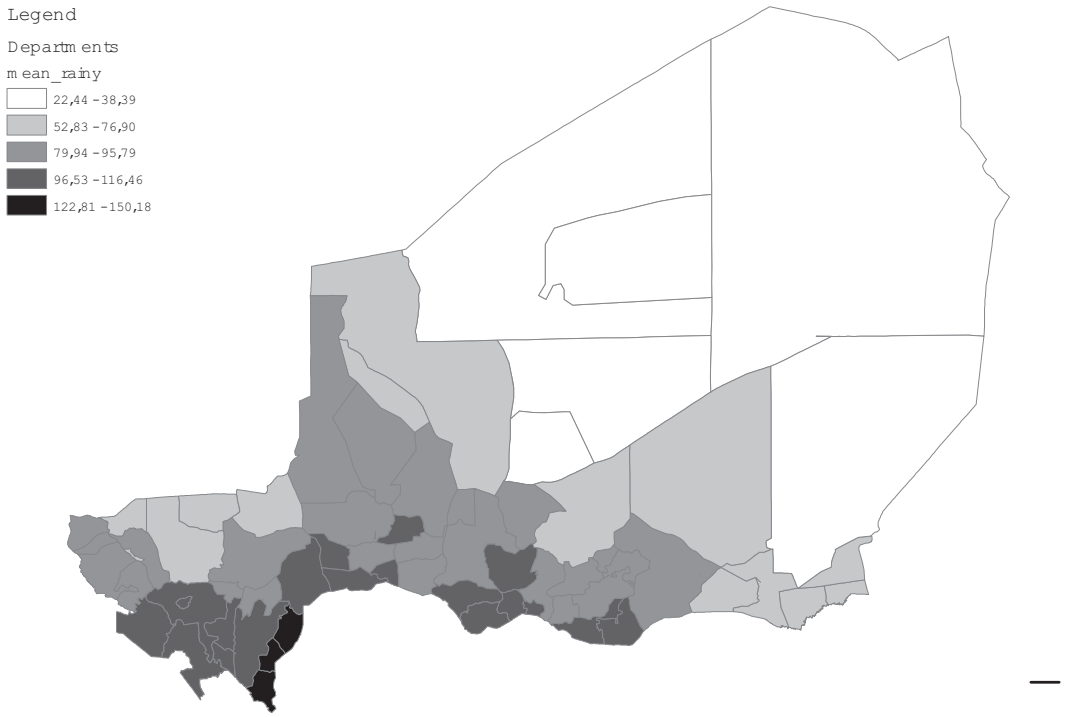

Figure 2. Spatial distribution of precipitations in the growing season over the period 1983–2012. *Source:* authors' elaborations based on ARC2 database.

available given the increasing food needs. Some concern dates back to the 1990–2000 period in which farmland increased by 20% whereas the population increased by more than 40%, resulting in a net decrease in food availability (FAO, 2015). The geographical context is mainly responsible for this negative performance since only 15% of Niger's land is arable and located in a region mainly along its southern border with Nigeria. Millet, sorghum, and cowpea constitute the principal rainfed subsistence crops and the principal sources of energy for the rural population.

Specific attention needs to be given to Niger's climatic conditions which are characterized by significant variability within the country according to the type of agro-ecological zones (AEZs) that characterize the country. Even though the transition is not clear-cut, Niger covers three main AEZs: Saharan, Sahelian and Sudanese, which imply high variability in temperature and rainfall. Niger's seasonality is divided into dry and rainy seasons. During the latter, which typically occurs between May and September, Niger as a whole receives more than 500 millimeters of rain which provides enough water for crops and livestock (USGS, 2012). However, long-run analyses detect a growth in summer rains occurring over the past 20 years, expanding the areas of Sahel in which most of the rainfall concentrates. On the other hand, the increase in rainfall has also been accompanied by an increase in average temperatures (+0.6 Celsius, on average, since 1975[3]) which has amplified the effects of droughts with negative impacts on food security due to reduced crop harvests and pasture availability (Shanahan, 2009; Snorek, Renaud, & Kloos, 2014). In this respect, Figure 1 plots density functions of the average rainfall level registered in each month of the growing season and provides a sharp comparison between long-run changes occurring between 1983–2000 and 2001–2012. At the spatial level (Figure 2), the distribution of rainfalls in Niger in the growing season appears strongly heterogeneous. Most precipitations concentrate in the southern areas, whereas the northern territories accumulate on average less than 40 mm of monthly rain.

[3] Hoerling, Hurrell, Eischeid, and Phillips (2006) attribute the rainfall increases to the warming of the northern Atlantic Ocean.

Although the rain increase has supported large expansions of cultivation in Niger, helping to offset the rapid population growth, whether this increasing trend will persist also depends on climate change and still remains an open issue. However, future projections for the Sahel regions suggest uncertain climate in which the effects of warmer air temperatures could intensify the potential impact of drier climate (Biasutti *et al.*, 2008; Desanker & Magadza, 2001; Hengsdijk & van Kuelen, 2002). At the macroeconomic level, despite benefit from the IMF 2012–15 Extended Credit Facility Agreement, Niger is still a highly vulnerable country and its growth expectation remains a challenge, given the limited domestic markets, prices fluctuation, access to credit, low degree of competitiveness, and economic activity diversification as well as the impact of climate and other adverse events in the agricultural sector (IMF International Monetary Fund, 2014). Pushing productivity gains in wetter Nigerien areas may represent an easier option than extending agriculture into more marginal areas, but the rapid population growth may make it difficult to slow the process of agricultural extension into marginal areas (Boserup, 1975). In addition, institutional support – largely relevant to the adaptive capacity of a country (Brooks & Adger, 2004; Engle, 2011; Gupta *et al.*, 2010), seems to have produced limited benefits for the Nigerien population (Snorek *et al.*, 2014).

4. Data description

In order to determine the drivers and the welfare effects of diversification practices in Niger, we exploit original panel socio-economic data obtained from the Niger National Survey on Living Conditions and Agriculture (ECVM/A).[4] We build a longitudinal dataset by appending information obtained from the first survey visit in 2011/2012 with those obtained from the second visit in 2014.

The ECVM/A is an integrated multi-topic HH survey which provides rich information for evaluating poverty and living conditions in Niger. The surveys were implemented by the Niger National Institute of Statistics with technical and financial assistance from the World Bank. Each wave envisages two visits, the first one during the planting season, and the second one during the harvest season. The HH and agriculture/livestock questionnaires, as well as the community/price questionnaire, are administered during the first visit whereas during the second visit, only the HH and agriculture/livestock questionnaires are administered. The ECVM/A has been designed to have national coverage, including both urban and rural areas in all regions of the country, with a fine spatial breakdown including 270 enumeration areas (EA). HHs visited in 2011 were re-visited in 2014.[5]

Even though the longitudinal component of our panel includes only two periods, we can benefit from a richness of information to build detailed HH profiles. Moreover, to the best of our knowledge, this is the first study that employs a representative socio-economic panel dataset for Niger. We combine this valuable dataset with granular information on precipitation collected at EA level every ten days (decadal). Weather data derive from the Africa Rainfall Climatology Version 2 (ARC2) database and cover the 1983–2014 period.[6] Given our main focus on the diversification practices as a possible livelihood strategy for the most vulnerable communities, we exclude HHs living in urban areas. In order to keep our panel balanced, we also limited the sample to HHs that had not moved between the interview periods. Our final sample includes 1672 rural HHs, observed in 2011/2012 and 2014, and distributed across 124 EAs[7] over seven administrative regions, which correspond to 3344 observations available for analysis.

The richness of this dataset allows us to pinpoint a set of diversification indices and welfare outcomes. In so doing, we follow the Sustainable Rural Livelihood framework described in Section 2 and classify the selected covariates representing the HHs' assets endowment. Table 1 reports the mean and the standard deviations, by survey year, of selected variables.

Given that the diversification strategies result in a variety of practices affecting different income sources, we first distinguish between diversification in crop species and labor diversification. We employ three different indices of diversification to validate the robust impact of different dimensions of diversification on welfare. The simple Count measures the richness of crops cultivated and sources of labor on which the HH relies; the Berger-Parker index captures the relative abundance, and the Shannon-Weaver index accounts for the evenness or proportional abundance (for a review of the pros and cons of each index, see Duelli & Obrist, 2003). Table 4 in Appendix provides information on the calculation of the indices and their interpretation. For crop diversification, the indices are based on the number of cultivated crop species adjusted by land size at plot level. For labor diversification, we calculate the number of different work activities by defining 11 different jobs, also disentangling skilled and unskilled workers[8] aged between 14 and 65. This classification results in 22 labor differentiations. Table 1 shows that all the diversification measures decreased, with the exception of the Shannon crop, during 2011–14.

The choice of welfare outcomes W follows multidimensional metrics. Accordingly, the second-stage quantile models, described in Section 5, include the total HH income expressed in US 2010 dollars and dietary energy supply (DES) expressed in total calories per day. Each of these indicators provides information on distinct aspects of the HH welfare, with income representing a basic standard measure and DES signaling a potential deficit in food security (Sahn & Stifel, 2003). Also in this case we observe a decrease in 2014 which is even more severe when DES is observed.

The set of endowment covariates is represented by a vector K of different capital endowments. The natural capital includes rainfed land (Nguyen *et al.*, 2017) expressed in hectares and the Tropical Livestock Unit (TLU) index. While a large share of rainfed land is expected to increase crop diversification because the risk aversion on vulnerable lands is higher (Di Falco & Chavas, 2006), the endowment of TLU can generate a variety of different on-farm activities, such as dairy and butchery, which create competition for labor with mere crop cultivation (Shiferaw, Menale, Moti, & Chilot, 2013; Teklewold, Kassie, Shiferaw, & Köhlin, 2013), but it may also incentivize other non-farm activities such as small commercial enterprises (Moll, 2005).

The count of technological (e.g., tractors and machineries) and non-technological agricultural inputs (e.g., shovels, spades), together with the adoption of modern crop varieties, are widely utilized as proxies for the physical agricultural capital (Gollin, Parente, & Rogerson, 2002). Since the use of non-technological assets is associated with traditional agriculture, the prevalence of technological assets is likely to define the level of investments in intensive agriculture (Drucker & Rodriguez, 2009; Omer, Pascual, & Russell, 2007). Intensification, in a broad sense, is expected to enhance the ability of farmers to sustain modern agricultural

[4] Enquête National sur les Conditions de Vie des Ménages et Agriculture.

[5] HHs and individuals who moved after the 2011 survey were tracked. When the entire HH moved within Niger, the HH was found and re-interviewed in 2014. HHs that moved outside Niger were not followed.

[6] The ARC2, an improved version of the ARC1, combines inputs from two sources: (i) 3-hourly geostationary infrared (IR) data centered on Africa from the European Organization for the Exploitation of Meteorological Satellites (EUMETSAT) and (ii) quality controlled Global Telecommunication System (GTS) gauge observations reporting 24-h rainfall accumulations over Africa. For further details, see Novella and Thiaw (2013).

[7] More than 40% of the sample lies in desert regions.

[8] We assume that HH members can choose between investing in skilled or unskilled activities.

Table 1
Descriptive statistics for selected variables

Variables	2011		2014	
	Mean	SD	Mean	SD
Diversification				
Crop divers. (Count)	3.04	1.26	2.92	1.14
Labor divers. (Count)	3.82	2.40	3.74	2.36
Crop divers. (Berger-Parker)	2.32	0.91	2.29	0.87
Labor divers. (Berger-Parker)	1.17	0.31	1.06	0.20
Crop divers. (Shannon-Weaver)	1.88	0.61	2.59	1.01
Labor divers. (Shannon-Weaver)	1.28	0.47	1.09	0.30
Welfare				
Total income in USD ($\times$1000)	1.79	2.01	1.59	4.17
Dietary energy supply (DES) (cal/pc/day $\times$ 1000)	2.64	1.03	1.65	0.79
Natural capital				
Rainfed cultivated land (ha)	4.18	3.78	3.03	8.49
Tropical Livestock Unit (TLU)	1.37	2.51	0.96	2.00
Physical capital				
Agric. technology assets (n)	0.05	0.27	0.10	0.40
Agric. non-technology assets (n)	8.19	4.27	9.51	4.72
Adoption of MVs (1 = yes)	0.16	0.37	0.17	0.39
Human capital				
HH size (n)	6.77	3.39	6.74	3.27
Ave. HH education (years)	2.82	4.65	3.20	4.51
HH with female head (1 = yes)	0.07	0.25	0.10	0.32
HH head age (years)	44.25	14.33	46.84	13.98
Financial capital				
Ave. distance to bank (km)	29.52	37.03	40.92	45.95
Social Capital				
Transportation means (n)	3.65	2.97	3.16	2.95
ICT technologies (n)	1.04	1.12	2.64	2.47
Shocks				
SPI $\leq$ 1 (1 = drought)	0.01	0.09	0.00	0.00
SPI > 1 (1 = rainfall)	0.75	0.43	0.76	0.42
Input price shock (1 = yes)	0.06	0.24	0.06	0.24
Food price shock (1 = yes)	0.15	0.36	0.06	0.25

practices that aim to maximize productivity rather than relying on risk minimization strategy. Although such an approach could reduce the allocation of labor to other off-farm activities when the HH increases its specialization in on-farm activities (Ruben & Pender, 2004), it may also be a driver for reducing crop diversification if we consider that the intensification is associated with both adoption of modern varieties (MVs) in mono-cropping systems and an abandonment of local landraces cultivation (Di Falco & Perrings, 2003; Pascual & Perrings, 2007). Nevertheless, traditionally, in SSA, the adoption of MVs is often subsidized, and marginal and smallholders with poor financial and social capital could fail to implement the appropriate intensification strategy required to let the technology outperform on local varieties, as also demonstrated by the small endowment of technological assets. These failures also make it possible to observe MVs mixed with other local crops in a diversified system (Coromaldi, Pallante, & Savastano, 2015). In Table 1, we notice that the share of adopter HHs constitutes a small and constant fraction in Niger and this partly depends on the absence of a specific national subsidy policy that is, on the other hand, typical of other SSA countries such as Malawi or Ethiopia (Chibwana, Fisher, & Shively, 2012; Rashid, Tefera, Minot, & Ayele, 2013). This variable is calculated by assigning a value of 1 to farmers that use a modern crop seed on at least one plot of their field. The statistic covers any type of crop (with a significant presence of MVs observed only for cowpea, millet, sorghum and rice), placing Niger among the SSA countries with the lowest shares of adoption.

The human capital is here represented by HH size, education, age and gender of HH head. A higher endowment of human capital is expected to increase the options for both skilled and unskilled labor diversification whereas the impact on crops could be driven indirectly by income smoothing deriving from the additional wage for off-farm labor (Nguyen *et al.*, 2017; Reardon, 1997). With respect to the gender issue, the empirical literature does not seem to provide clear-cut information on heterogeneous diversification behaviors when gender differentiations are considered (Doss, 2002). Some authors point out that income inequality can clearly play a negative role when women decide to adopt diversification practices, despite female HHs showing a high degree of risk aversion (Covarrubias, 2015; Dercon, 1996). This may imply that there is less money to be invested in order to cover start-up costs (Reardon, 1997) and lower bargaining power in the case of labor diversification (Evans, 1992). Further differences in diversification behavior can derive from inequalities in education and skills as well as cultural local norms (Glick & Sahn, 1997; Qian, 2008).

The financial capital is here represented by the distance from the main bank as a proxy for credit and market access (Beck, Demirgüç-Kunt, & Honohan, 2009). Credit has been found to reduce vulnerability and, consequently, the degree of risk aversion. At the same time, larger credit can also sustain investments in agricultural technological inputs or education, thereby resulting in labor diversity gains to repay the loans which come at the expense of loss in crop diversification (Barrett *et al.*, 2001; Swaminathan, Du Bois, & Findeis, 2010; Winter-Nelson & Temu, 2005).

Finally, we use the endowments of ICT technologies (TVs, mobiles, radios, computers, etc.) and transportation assets (e.g., bicycles, cars) as proxies for the social capital and networking capacity. There is robust empirical evidence suggesting that spatial proximity favors market and information access, thus facilitating the labor diversification process (Fafchamps & Shilpi, 2003;

Lanjouw *et al.*, 2001; Davis *et al.*, 2010). Moreover, ICTs provide opportunities for the top-down dissemination of precious pieces of knowledge such as weather forecasts, hazard warnings, market information, job opportunities, and advisory services. Nevertheless, this is expected to be conditional on the quality of the flow of information and the human capital of recipients (e.g., education), rather than sufficient infrastructural support.

As pointed out previously, according to livelihood options, climatic anomalies are an important driver of diversification outcomes, depending on the type and duration of variability to which HHs have been exposed. In this respect, a remarkable feature of our study is constituted by the granular climate data which allow a climate identification of climate patterns that is finer than previous studies (Ersado, 2003; Nhemachena & Hassan, 2007). To do this, we rely on the Standard Precipitation Index (SPI). The SPI is a widely used indicator in climatic science,[9] which allows significant variations in precipitations to be detected with respect to the long-run mean. The SPI fits raw precipitation data to a gamma or Pearson Type III distribution which is then transformed to a normal distribution (see Guttman, 1999 for further details). The use of SPI presents some advantages over other methods. First, in order to identify climate anomalies, only time-series data on precipitation are required. Moreover, the SPI is an index based on the probability of recording a given amount of precipitation. Since the probabilities are standardized, a value of zero indicates the median precipitation amount (half of the historical precipitation amounts are below the median, and half are above the median), thus the index is negative for drought, and positive for wet conditions. As the dry or wet conditions become more severe, the index becomes more negative or positive, ranging within a commonly-used scale from −2.5 to +2.5 standard deviations (s.d.) (WMO, 2012). The characteristic of being standardized provides a straightforward interpretation and allows for a fully indexed comparison over time and space. Moreover, the index is able to capture both short-term and long-term anomalies depending on the time scale over which it is calculated. In this study, our interest is in capturing potential climate anomalies in the most delicate period for farmers which occurs during the growing season which in Niger lies in the period May-September. Using our historical precipitation data, we thus calculate the SPI on a six-month basis to precisely map the seasonal precipitation pattern which is presented in Figure 3 averaged over EAs. By considering the minimum and maximum SPI values, some extreme events can be detected even though the period included between the first survey and last available precipitation data is characterized by moderate droughts and abundant rain. On the contrary, when considering the first wave period (2011–12), the drought was much more severe (on a monthly basis, the minimum SPI signals values lower than −3 s.d., with an average value of about −1 s.d.). Building on this evidence, the climate dummies are calculated by considering index values larger than 1 s.d. for precipitation events and lower than −1 s.d. for drought shocks that occurred only during the months in the growing season.[10] Moreover, in line with our conceptual framework, the hypothesis of a climate-induced adaptation process via diversification is tested by considering the time window May-September for the previous five years of each wave.[11]

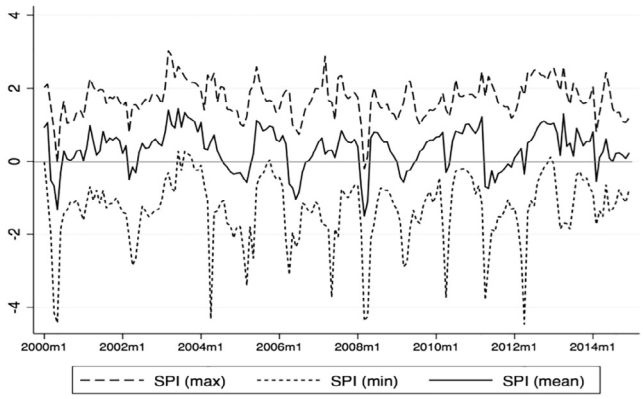

Figure 3. Six-month SPI averaged over Niger EAs from 1983 to 2014. *Source:* authors' elaborations based on ARC2 database.

Finally, the impact of market fluctuations is captured by two dummy variables, signaling whether HHs experienced high agricultural input and food prices[12] in the previous year. Although market shocks can prevent farmers from enhancing the level of intensification during the planting season, these events also undermine food security and are likely to increase crop diversification for subsistence reasons (Ellis, 1998). Market shocks could also be drivers of *ex-post* labor diversification to smooth the variability of income, particularly when food prices fluctuate (Kelly & Adger, 2000).

Preliminary evidence based on unconditional analysis on diversification indices and welfare outcome signals that the degree of diversification changes according to the welfare level. For instance, in the case of income (Figure 4), labor diversification measured by the Count index follows a reverse U-shaped curve, suggesting that the diversification level is higher in middle-income rural HHs. On the contrary, when labor diversification is measured using the Shannon-Weaver index (Figure 5) which accounts for evenness, a monotonic trend appears. In line with our empirical strategy, this evidence not only suggests measuring the impact of diversification conditioned to different welfare ranges, but also justifies the choice of using different diversification measures.

5. Empirical strategy

In line with the conceptual framework described in Section 2, several empirical concerns have to be addressed when estimating the drivers and effects of diversification. First, it is important to simultaneously account for common factors that may affect the two types of diversification under scrutiny, namely crop and labor diversification. As explained, the combination of these factors can give rise to different diversification patterns depending on the degree of complementarity or substitutability mechanisms that exist in HHs' diversification mixes. In this case, separate estimations would not exploit the information deriving from the entire set of common covariates, represented by assets endowment, in

[9] The SPI was recommended through the Lincoln Declaration on Drought as the internationally preferred index for meteorological drought (see Hayes, Svoboda, Wall, & Widhalm, 2011). However, an even better indicator is constituted by the SPEI (Standardized Precipitation Evapotranspiration Index) (Vicente-Serrano, Beguería, & López-Moreno, 2010), an extension of the SPI which also accounts for evapotranspiration, i.e., the water retaining capacity of the soil. This index is becoming popular in economics studies focusing on climatic variability (Bozzola, Smale, & Di Falco, 2017). Unfortunately, the calculation of this latter requires at least latitude values at EA level for which we do not have information.

[10] In order to characterize extreme climate events using the SPI, the World Meteorological Organization provides explicit recommendations. Accordingly, "drought is considered to have started when the SPI index value is ≤ -1.0 and ends when the SPI value becomes positive". For further details, see WMO (2015).

[11] We also tested the effect of short-run coping strategies by considering contemporaneous and one-year lagged climate shocks which resulted in non-significant coefficients. This evidence points to a role of diversification as a mid-term adaptation strategy in response to an observed persistence of climatic variability and stresses the difference with coping activities implemented to adjust shocks perceived as random.

[12] The correlations between the variables used for drought and rainfall shock and input price shock are −0.014 and −0.011, respectively; those between drought and rainfall shock and input price shock are 0.035 and 0.053. Thus, the three shocks, i.e., climate, input prices, and crop disease are not affected by correlation and can be included in the same model equation.

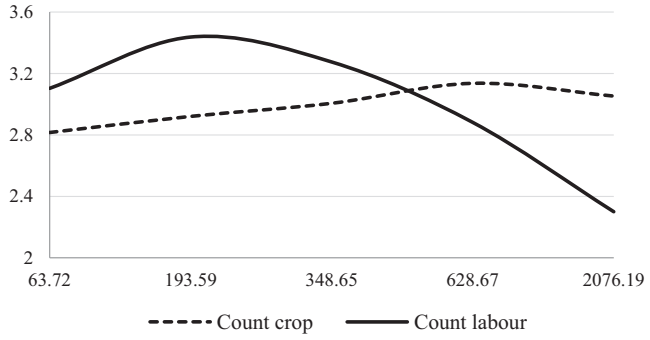

Figure 4. Diversification degree (Count) vs. per-capita income in USD in 2012.

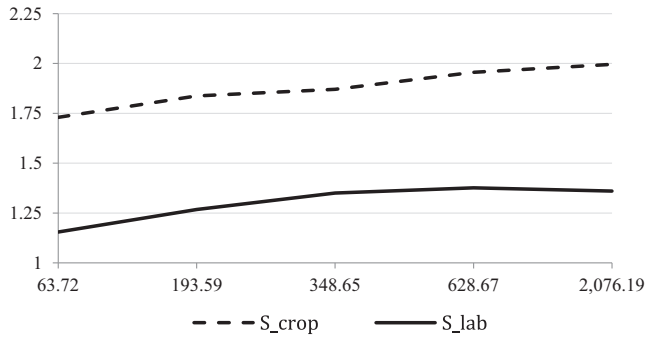

Figure 5. Diversification degree (with Shannon-Weaver index) vs. per-capita income in USD in 2012.

terms of correlation existing in the error terms. In this respect, an effective empirical approach that accounts for simultaneous dynamics is the well-known Seemingly Unrelated Regression (SUR) model (Zellner, 1962), which provides efficient estimates assuming error correlations across the different equations. This modeling choice has been already successfully adopted in the analysis of diversification strategies in a panel setting (Nguyen *et al.*, 2017).

At the same time, it is worth investigating whether diversification produces non-linear responses in HH welfare. As previously explained, diversification can produce impacts that are sensitive to different classes of welfare distribution. The best empirical solution to this issue is a model which provides quantiles of conditional distribution of the response variable expressed as functions of observed covariates. The empirical challenge represented by accounting for all these potential issues is also enriched by the existence of potential endogeneity given by the reverse causality between the welfare outcome variables and the diversification variables (Asmah, 2011; Ersado, 2003). Moreover, the panel nature of our data represents a further econometric challenge to account for.

We solve the empirical puzzle by employing the Two-Stage Residual Inclusion (2SRI) approach developed by Terza, Basu, & Rathouz (2008). This procedure includes a first stage obtained by regressing the endogenous variable, the diversification indices, on a set of instrumental and additional covariates. In our case, this first stage is obtained by means of a panel two-equation SUR model to account for in-error correlation between crop and labor diversification equations, augmented with Mundlak means to control for time-invariant unobserved heterogeneity and avoid the incidental parameter problem given the short longitudinal component[13] (Lancaster, 2002; Neyman & Scott, 1948). For HH $i = 1, \ldots N$ and year $t = 1, 2$, the estimated random effects panel model is as follows:

$$\boldsymbol{D}_{it,j} = \beta_j \mathbf{K}_{it,j} + \gamma_j \mathbf{S}^{\boldsymbol{C}}_{At-\tau,j} + \eta_j \mathbf{S}^{\boldsymbol{P}}_{it-1,j} + \mu_j \overline{\mathbf{M}}_{\mathbf{i}} + \boldsymbol{z}_{\mathbf{it,j}} \tag{5}$$

where $j = crop, lab$ indexes the two equations for crop and labor diversification respectively represented by the vectors $\boldsymbol{D}$ as described in Section 4 and calculated following Table 4; $\mathbf{K}_{it}$ is a vector of asset endowments at HH level which includes natural capital, physical capital, human capital, financial capital, and social capital. $\mathbf{S}$ is a vector of exogenous dummies capturing climate anomalies at enumeration area, A, level and during the time span $\tau = (1, \ldots, 5)$, $\boldsymbol{P}$ includes a vector of dummies at HH level and signaling, respectively, exogenous input price and food price shocks experienced by the HH during the past year. $\overline{\mathbf{M}}_{\mathbf{i}}$ includes a vector of Mundlak means given by

$$\overline{\mathbf{M}_{\boldsymbol{i}}} = [\bar{\mathbf{K}}_{i,j}, \bar{\mathbf{S}}_{A,j}] \tag{6}$$

where

$$\bar{\mathbf{K}}_{i,j} = \frac{1}{T_i} \sum_{t=1}^{T_i} \mathbf{K}_{it,j}, \tag{7}$$

$$\frac{1}{T_A} \sum_{t=1}^{T_A} \mathbf{S}^{\boldsymbol{C}}_{At,j} \tag{8}$$

$$\frac{1}{T_i} \sum_{t=1}^{T_i} \mathbf{S}^{\boldsymbol{P}}_{it-1,j}. \tag{9}$$

Finally, $\beta, \gamma, \boldsymbol{\eta}$, and μ are unknown parameters to be estimated for each j. The errors $\boldsymbol{z}$ are assumed to be correlated across the crop and labor diversification equations with overall variance–covariance matrix

$$\Omega = E(zz') = \sum \otimes I_N. \tag{10}$$

The second stage is implemented by employing a two-wave pooled quantile model (Koenker & Hallock, 2001) given by[14]:

$$W_{it} = \delta_{0,it} + \delta_1 D^{crop}_{it} + \delta_2 D^{lab}_{it} + \delta_3 \widehat{D^{crop}_{it}} + \delta_4 \widehat{D^{lab}_{it}} + \delta_5 \mathbf{K}_{it} + \varepsilon_{it} \tag{11}$$

where the dependent variable W_{it}, described by Formula (2) in Section 2, the HH welfare, which is conditioned to four sections of the distribution ($q = \{0.2, 0.4, 0.6, 0.8\}$). In order to provide a richer representation of the HH conditions, we employ total income and DES, as introduced in Section 4, as welfare outcomes. Moreover, $\hat{D}^{crop}$ and $\hat{D}^{lab}$ include, respectively, the residuals of crop and labor diversification equation obtained from model (5), which correct for potential endogeneity between the welfare outcome and diversification variable. As in the SUR model previously described, $\mathbf{K}_{it}$ is a vector of asset endowments at HH level which includes natural capital, physical capital, human capital, financial capital, and social capital; δ_n for $n = 0 \ldots N$ are unknown parameters to be estimated. We estimate the model described in Eq. (11) separately for income and DES by means of maximum likelihood.

[13] The incidental parameter problem may cause inconsistency bias given that the pane SUR model is estimated via maximum likelihood. We employ the *xtsur* Stata command developed by Nguyen M. C. (2008).

[14] It is worth noting that the estimation of fixed-effects panel quantile models is not straightforward. The reason lies on the fact that standard demeaning transformation is a linear operator, "a property that is not shared by conditional quantiles" (Abrevaya & Dahl, 2008, p. 381). When T is small (i.e., $T < 5$), a robust method for model identification is even more complicated and still constitutes an empirical issue (see, for instance, Abrevaya & Dahl, 2001; Canay, 2011; Chernozhukov & Fernández-Val, 2011; Koenker & Hallock, 2001 among others). In light of this, we prefer a more cautious and robust approach by employing a pooled estimator which includes the time dummy with standard errors clustered at EA level. This comes at the expense of accounting for potential unobserved heterogeneity by means of fixed effects panel estimators.

6. Results and discussion

(a). Determinants of diversification

The outcomes obtained by the SUR model are presented in Table 2 in which columns (1), (2), and (3) report respectively the estimates for Count, Berger-Parker and the Shannon-Weaver indices of diversification. A first robust result, with the exception of the Berger-Parker where the coefficients are not significant, is represented by the impact of weather anomalies. Our estimates point to an incentivizing effect of drought on farmers' activity which enlarges their diversity both in terms of richness and evenness. The size of impact is large and confirms how crop diversification is utilized as an adaptation strategy against adverse weather events perceived by HHs as persistent in the mid-run. In this respect, diversification configures as a strategy that ensures farmers rely on a set of locally adapted varieties which are resistant to degraded and poor soils on rainfed land (Bellon, 2004; Lipper & Cooper, 2008). This hypothesis also finds support by considering the coefficient of MVs' adoption, which constitutes a negative driver of crop diversification, since these technologies outperform in intensive and monocropping cultures (Pascual & Perrings, 2007), whereas the amount of rainfed land explains a higher degree of both crop richness and evenness. In order to better disentangle the trade-off between intensification and the degree of crop varieties, we introduce an interaction term that includes the amount of cultivated land and a dummy variable indicating the adoption of MVs, but we do not find robust evidence on this interaction.

Consistently with crop diversification, the degree of labor diversification is also affected by climate anomalies. However, we find a reverse pattern since a higher level of labor diversification seems to be spurred by an abundance in rainfall and not by a drier climate. As mentioned in the conceptual framework, given the complementarity mechanisms existing between crop and labor diversification, this result can be interpreted as an *ex-post* reaction to a perceived positive variation of climate conditions. In this case, farmers account for a larger rainy provision on rainfed-based agriculture in regions with historically low levels of rain, which may translate in more productive lands and incentivize HHs to allocate, at the margin, additional time to off-farm activities (Dile, Karlberg, Temesgen, & Rockström, 2013; Jayachandran, 2006). This hypothesis is strengthened by observing the impact of human capital, prox-

Table 2
Drivers of diversification (comparison across indices)—SUR estimates

	Count		Berger-Parker		Shannon-Weaver	
	Crop	Labor	Crop	Labor	Crop	Labor
Natural capital						
Rainfed cultivated land	0.0053**	0.0020	0.0014	0.0013	0.0127***	−0.0129**
	(0.0028)	(0.0014)	(0.0028)	(0.0009)	(0.0038)	(0.0060)
Tropical Livestock Unit (TLU)	0.0339***	0.0085*	0.0120	0.0070**	0.0153	0.0296*
	(0.009)	(0.0046)	(0.009)	(0.0031)	(0.0122)	(0.0161)
Human capital						
HH size	0.0234*	0.0295***	0.0117	0.0174***	0.0030	−0.006
	(0.0126)	(0.0064)	(0.0125)	(0.0044)	(0.0070)	(0.0110)
Ave. HH edu. years	−0.0106**	−0.0012	−0.0051	−0.0000	−0.4210***	−0.1090
	(0.0052)	(0.0026)	(0.0052)	(0.0018)	(0.1300)	(0.2050)
HH head age	−0.0058	0.0008	0.0003	−0.0002	0.0038	0.4480***
	(0.0036)	(0.0018)	(0.0035)	(0.0012)	(0.0169)	(0.0266)
HH with female head	−0.3060***	0.0050	−0.1910**	−0.0059	0.0432***	−0.0546***
	(0.0965)	(0.0493)	(0.0963)	(0.0336)	(0.0122)	(0.0192)
Physical capital						
Agric. technology assets	−0.0595	0.0877***	0.0351	0.0699***	0.1510*	0.0749
	(0.0637)	(0.0325)	(0.0635)	(0.0222)	(0.0857)	(0.135)
Agric. non-technology assets	0.0072*	−0.0025	0.0033	−0.0023	0.0152**	0.0457***
	(0.0042)	(0.0027)	(0.0052)	(0.0018)	(0.007)	(0.0111)
Adoption of modern varieties (MVs)	−0.1040*	0.0553**	−0.0277	0.0353*	−0.1560**	0.1200*
	(0.0530)	(0.0271)	(0.0529)	(0.0185)	(0.0074)	(0.1120)
Rainfed cult. land × MVs	−0.0052	0.0017	0.0032	0.0008	−0.0029	0.0166
	(0.0080)	(0.0040)	(0.0079)	(0.0027)	(0.0107)	(0.0168)
Financial capital						
Ave. distance to bank	0.0012**	0.0004*	0.0010**	0.0003*	0.0010*	0.0003
	(0.0005)	(0.0002)	(0.0004)	(0.0001)	(0.0006)	(0.001)
Social capital						
Transportation means	0.0090	0.0126***	0.0040	0.0093***	−0.0043	0.0133*
	(0.0090)	(0.0046)	(0.0090)	(0.0031)	(0.0048)	(0.0076)
ICT technologies	−0.0080	−0.0205***	−0.0025	−0.0145***	−0.0170	−0.0003
	(0.0118)	(0.0060)	(0.0118)	(0.0041)	(0.0159)	(0.0250)
Shocks						
SPI ≤ 1	0.7790***	0.0051	0.2930	0.0303	1.3200***	−0.6190
	(0.2660)	(0.136)	(0.2660)	(0.0928)	(0.359)	(0.5650)
SPI > 1	0.0770	0.0510**	0.0547	0.0367**	−0.0324	0.2910**
	(0.0541)	(0.0260)	(0.0540)	(0.0179)	(0.0728)	(0.1150)
Input price shock	0.0496	0.0505*	0.0476	0.0412*	0.0159	0.0282*
	(0.0704)	(0.0300)	(0.0702)	(0.0245)	(0.0947)	(0.1490)
Food price shock	0.0583*	0.0113	0.0906**	0.0055	0.0484	0.1470*
	(0.0338)	(0.0198)	(0.0387)	(0.0135)	(0.0523)	(0.0823)
Mundlak means			YES			
Year dummy			YES			
N			3344			

Notes: Standard errors clustered at EA level in parentheses. Significance level: *$p < 0.1$, **$p < 0.05$, ***$p < 0.01$

ied by the HH size variable, which shows a positive impact on both Count and Berger-Parker diversity. On the other hand, education does not constitute a significant diversification driver and this could be caused by the low demand for skilled employment observed in rural areas of developing countries (Lowell & Findlay, 2001).

Similar interpretation can be provided to explain the impact of higher endowments of physical agricultural capital, the technological one in particular (see the agricultural technology assets and the MVs' coefficients), which being likely to substitute the labor on-farm can, *ceteris paribus*, incentivize HHs to allocate time to off-farm activities.

As expected, we also find that an increase in agricultural inputs and food prices are significant and positive drivers for both labor and crop diversity. The effect of these short-term market fluctuations provides farmers with the incentive to rely on crop diversification as both substitute inputs for modern agricultural inputs (chemical fertilizers or pesticides) and as a source of self-produced food as well as on labor diversification in order to smooth the potential unexpected adverse effect on income.

The other results are characterized by a less consistent pattern across the three diversification indices. The female-headed HHs are less likely to diversify labor (column 3). However, this result is not robust since the Shannon crop diversity signals an opposite direction for HHs. A potential explanation channel could be given by considering that the evenness, in contrast with a pure Count measure, is a more suitable measure of representing the risk spreading of a portfolio of crops. Since female HHs are found to have a higher degree of risk aversion, we are not surprised to find such contrasting evidence (Covarrubias, 2015; Doss, 2002).

Unexpectedly, our results point to a non-univocal role of technological social capital. In the case of labor, the coefficients associated with access to social capital are negative and significant whereas for crop diversification they are not significant. The ICTs are expected to favor the communication process among individuals and facilitate social interaction. Indeed, ICTs may constitute precious tools for capturing pieces of knowledge such as job offers and other opportunities that can positively affect labor diversification. At the same time, ICTs can also play an effective role in informing people of local weather forecasts, thus enhancing an awareness of the risks of extreme weather events. However, both these hypotheses cannot be confirmed in our analysis of diversification determinants. A potential justification is given by the strong need of ICTs to be supported by infrastructures (electricity, signal coverage for mobile devices) and by a 'social network effect' that is achieved only when a multitude of people use the ICT devices. In our case, only a very small fraction of rural HHs has access to electricity (3.2%) and owns a (probably basic) mobile phone (54.1%), and this setting may strongly undermine the great potential usefulness of ICTs. On the other hand, we signal a positive and significant diversification impact provided by means of transportations such as cars or bicycles. Even though this result is not consistent across the two diversification strategies, it partially compensates for the negative influence of ICTs in the case of labor diversification. On the contrary, a larger endowment of financial capital, here represented by access to credit, incentivizes both crop and labor diversification, even though this impact is not significant when considering the labor Shannon index.

(b). Effect of diversification on welfare

In this section, we present the results of the impact of diversification on the HH welfare as represented by the two proxies employed, namely total income and DES, and deriving from estimating model (11). The coefficients represent semi-elasticity and standard errors are clustered at enumeration area level. Table 3 presents point coefficient estimates measuring the impact of crop and labor diversification on four different quantiles of the welfare outcomes, whereas in the Appendix, Tables A2–A4 reports the full set of results.

The impacts of diversification are heterogeneous, varying across the different welfare classes and depending on the different dimensions of welfare measures, thereby justifying the use of quantile regressions to catch the non-linear effects of diversification. However, some consistent patterns can be identified across the distributions of both welfare measures.

The principal and more robust result is the significant impact of crop diversification on both income and DES. All the three diversity indices show that crop diversification mainly benefits the most vulnerable HHs, since the impacts decrease along the welfare distribution. In particular, the size of the impact on the poorest group ranges from double (see Count) to triple (see Shannon) the impact on the richest group.

Labor diversity has a positive and significant impact on income. We also note that, while diversification can be a deliberate strategy of proactive well-endowed farmers given that more options are available as is the case of the so-called progressive diversification (Martin & Lorenzen, 2016), this impact shows, consistently with crop diversification, decreasing marginal effects along the income distribution. Nevertheless, the simple Count of labor activities is far from being significantly associated with welfare impacts. This could be explained with the particular dimension of the Count index which captures, in the case of labor, only the number of sources to which the HH allocates the labor supply. These include occasional, or also daily, off-farm activities which are likely to have a negligible direct impact on the amount of income gained by the HHs. On the contrary, measures of relative proportion such as the Berger-Parker and the Shannon assign a "weight" to the labor activities by directly linking them with the overall income gained (Hulme & Shepherd, 2003).

By comparing the impact of crop and labor diversification on DES, we can infer that while crop diversity enhances the portfolio of food available to the HHs by ensuring a constant amount of calorie intake, also in the case of potential climate and market adverse events, labor diversification can be perceived more as an income smoothing strategy. Labor diversity is indeed a significant and positive means of DES for the poorest HHs, with an effect that is consistent both for Shannon and Berger-Parker indices. According to the evidence provided for income and labor diversification, HHs are likely to allocate a greater portion of their income on food expenditure. Hence, it is not surprising to observe how labor diversification also has a positive effect on their food security. On the contrary, more endowed farmers characterized by a higher calorie intake are likely to allocate their diversification-induced income gains to other types of goods expenditure, with their energy intake remaining constant. The only exception to such a path is found on the fourth quantile of DES in the case of Shannon which can be explained with a non-linear variation in nutrient elasticity with respect to high income and for already satisfying calorie intake levels (Ecker & Qaim, 2011).

7. Concluding remarks

The present study sheds light on the diversification effects on Niger rural communities using unique panel data deriving from two national-representative survey waves carried out in 2011 and 2014. We focus on the mechanisms that trigger both crop and labor diversification practices in line with the Sustainable Rural Livelihood framework. We identify a series of common drivers that are able to cause effective diversification strategies. In particular, the endowment of cultivated rainfed land and livestock,

Table 3
Welfare effects of diversification: quantile regression

Diversification index	Income quantiles				DES quantiles			
	0.20	0.40	0.60	0.8	0.20	0.40	0.60	0.8
Count								
Crop	0.1210***	0.0868***	0.0747***	0.0682***	0.0337***	0.0242***	0.0230***	0.0209***
	(0.0265)	(0.0225)	(0.0186)	(0.0195)	(0.0114)	(0.0064)	(0.0056)	(0.0070)
Labor	−0.0070	−0.0228	−0.0114	−0.0166	−0.0074	−0.0032	−0.0053	−0.0053
	(0.0205)	(0.0151)	(0.0126)	(0.0143)	(0.0074)	(0.0044)	(0.0044)	(0.0044)
Berger-Parker								
Crop	0.1490***	0.0980***	0.1030***	0.0596**	0.0504***	0.0366***	0.0347***	0.0263***
	(0.0351)	(0.0258)	(0.0229)	(0.0295)	(0.0148)	(0.0090)	(0.0071)	(0.0090)
Labor	0.9980***	0.8290***	0.7500***	0.7110***	0.1100*	0.0181	0.0485	0.0409
	(0.1260)	(0.1040)	(0.1150)	(0.1200)	(0.0649)	(0.0402)	(0.0349)	(0.0380)
Shannon-Weaver								
Crop	0.2370***	0.1230***	0.1250***	0.0885**	0.0604***	0.0361***	0.0384***	0.0249**
	(0.0478)	(0.0288)	(0.0270)	(0.0379)	(0.0142)	(0.0098)	(0.0081)	(0.0097)
Labor	0.7300***	0.5850***	0.4800***	0.4600***	0.0798**	0.0251	0.0302	0.0422*
	(0.0830)	(0.0651)	(0.0705)	(0.0761)	(0.0383)	(0.0259)	(0.0206)	(0.0250)
N	3344				3344			

Notes: Standard errors in parentheses clustered at EA level, $^{*}p < 0.1$, $^{**}p < 0.05$, $^{***}p < 0.01$. Quantile model is estimated by means of *qreg2* Stata command by Parente & Silva (2016).

the size of the HH, the access to financial markets, the gender of the household head and the adoption of MVs of seeds are found to have an impact on both crop and labor diversification, even if differentiated according to the type of diversification dimension considered. Broadly speaking, we suggest the implementation of policies aimed at strengthening the most important diversification drivers, as identified in our analysis, which would constitute valid and efficient instruments to further increase household welfare. Considering the good adaptation response of Niger communities, by leveraging on the most important diversification drivers, the government would limit direct compensation mechanisms such as lump-sum payments that may generate reduced incentives to adopt virtuous autonomous strategies by less-responsive households with minimum government support.

Most importantly, our results point to a significant role played by climate variability which involves both crop and labor diversification and is consistent across three indices of diversification employed. In particular, a mid-run climate-induced adaptation process produces positive impacts on income and contributes to improving food security in terms of calorie intake gains. Moreover, our results unveil differentiated diversification effects across welfare distribution, with the poorest HHs benefitting the most. A substantive policy implication deriving from this evidence is that the impact of diversification practices, and crop diversification in particular, goes in the right direction when diversification is interpreted as a livelihood strategy for the most exposed, fragile population groups. However, this does not necessarily imply that for small sub-population groups, such as female-headed HHs, the impact may be differentiated. This hypothesis is warranted if considering the negative association between diversification and the positive effects of diversification in lower quantiles, where the group of female-headed HHs – one of the most fragile sub-population, should lie on.[15] This conclusion appears even more relevant if we consider the very limited policy support existing in rural Niger and highlights the autonomous and effective adaptation response undertaken by the poorest rural Nigerien communities. At the same time, the fact that we find smaller but still positive and significant welfare effects of diversification for well-endowed HHs signals the existence of progressive adaptation strategies which stress the importance of large traditional durable assets that induce an enrichment of the HH's activity portfolio. In this respect, welfare distribution can be identified as a potential channel for explaining these complementary mechanisms between risk-insurance strategies for most marginalized HHs and extra income allocation activity.

It is also worth highlighting how crop diversification is particularly relevant in guaranteeing vulnerable and poor HHs access to a decent calorie intake especially for coping, in the short run, with food price shocks. Policy interventions that aim to increase the value added of local variety cultivation, for instance through research and development or niche market development, could result in a win–win strategy for protecting farmers both from climatic variability and international food commodity price fluctuations. To this end, while enhancing the access to technological agricultural inputs could help to modernize agriculture, the exposure of rural households would be enhanced without a proper national safety-net or risk mitigating measures other than diversification.

Given the absence of the positive effects of HH's technological capital (ICTs *in primis*), desirable interventions aimed at reducing the adaptation deficit via diversification include more investments in infrastructures to support the penetration of ICTs which facilitate the diffusion of information on climate change risks and other items of knowledge. These would allow households to be more autonomous in undertaking diversification activities, reducing potential diversification lock-in due to climate change misperception and insufficient risk awareness and would also be a key to favoring a more efficient labor market.

Although this is the first study that addresses in a systematic way an analysis of diversification behavior and its effects in rural Nigerien communities, the results here presented are affected by some limitations which call for further investigation in the future. First, investments in terms of data are required to rely on a longer longitudinal dimension that is better able to address the issue of long-term adaptation (or transition) and the impact of diversification on resilience and rural livelihood. Moreover, given the absence of data for existing government interventions and other safety-net mechanisms, we do not provide evidence on the effectiveness of policy measures, although these target a very small fraction of Niger's population. The poorly significant role of social networks in raising a household's awareness of potential diversification benefits also points to a better investigation of the underlying reasons

[15] Female-headed HHs may include a substantive proportion of widowed HH heads, these latter constituting an even more fragile population group. For instance, Adelman and Peterman (2014) report that women in Uganda can be subject to loss of land rights (e.g., restrictions in land ownership) when a male landowner dies.

by also introducing alternative dimensions of welfare. Finally, the generalization of results should be made by comparing these with other relevant studies that apply the same framework and field of investigation. Hence, there is high scope for expanding this analysis to other SSA countries.

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Appendix A

Table 4
Calculation of diversification indices and summary statistics (*Source:* Smale, 2006; Asfaw et al., 2015)

Index	Interpretation	Formula	Range	Type	Note
Count	Richness	$D = B$	$D \geqslant 0$	Crop Labor	B is the number of crops planted by the HH. B is the number of HH income sources
Berger-Parker	Relative abundance	$D = 1/\max(\alpha_i)$	$D \geqslant 1$	Crop Labor	$max(\alpha_i)$ is the value of the maximum area share planted to the i-th crop $\max(\alpha_i)$ is the value of the maximum time share allocated to the i-th working activity performed by all HH members aged more than 14 years
Shannon-Weaver	Evenness, proportional abundance	$D = -\sum_i^{\alpha} \ln(\alpha_i)$	$D \geqslant 0$	Crop Labor	α_i is the area share planted to the i-th crop α_i is the time share allocated to the i-th working activity performed by all HH members aged more than 14 years

Table 5
Welfare effects of diversification (Count)

Covariates	Income quantiles				DES quantiles			
	0.20	0.40	0.60	0.80	0.20	0.40	0.60	0.80
Crop divers.	0.1213***	0.0868***	0.0747***	0.0682***	0.0337***	0.0242***	0.0230***	0.0209***
	(0.0376)	(0.0253)	(0.0217)	(0.0217)	(0.0112)	(0.0076)	(0.0072)	(0.0073)
Labor divers.	−0.0070	−0.0228	−0.0114	−0.0166	−0.0074	−0.0032	−0.0053	−0.0053
	(0.0240)	(0.0168)	(0.0137)	(0.0160)	(0.0070)	(0.0043)	(0.0044)	(0.0051)
Crop divers.—residuals	−0.0343*	−0.0068	−0.0011	−0.0115	−0.0078**	−0.0106***	−0.0086***	−0.0110***
	(0.0190)	(0.0125)	(0.0071)	(0.0103)	(0.0033)	(0.0024)	(0.0031)	(0.0024)
Labor divers.—residuals	−0.0289***	−0.0166**	−0.0073*	−0.0129***	0.0030	0.0029	0.0027	0.0031*
	(0.0098)	(0.0077)	(0.0044)	(0.0045)	(0.0029)	(0.0018)	(0.0020)	(0.0017)
Rainfed cultivated land	0.0030	−0.0025	0.0013	−0.0032	0.0009	0.0019**	0.0015	0.0009
	(0.0028)	(0.0042)	(0.0020)	(0.0023)	(0.0011)	(0.0009)	(0.0015)	(0.0009)
TLU	0.0819***	0.0740***	0.0724***	0.0756***	0.0052**	0.0026	0.0044	0.0145***
	(0.0210)	(0.0224)	(0.0171)	(0.0121)	(0.0023)	(0.0046)	(0.0056)	(0.0036)
Age of HH head	0.0063***	0.0031*	0.0004	−0.0028	0.0009	0.0006	0.0007	0.0011**
	(0.0020)	(0.0017)	(0.0015)	(0.0019)	(0.0012)	(0.0006)	(0.0005)	(0.0005)
HH size	0.0545***	0.0600***	0.0468***	0.0496***	−0.0751***	−0.0895***	−0.0920***	−0.0954***
	(0.0147)	(0.0116)	(0.0097)	(0.0136)	(0.0059)	(0.0035)	(0.0037)	(0.0040)
Ave. HH edu. years	0.0113*	0.0097*	0.0028	0.0088	0.0031	0.0002	−0.0009	0.0016
	(0.0060)	(0.0050)	(0.0052)	(0.0073)	(0.0025)	(0.0015)	(0.0016)	(0.0019)
HH with female head	−0.2689**	−0.3485***	−0.3414***	−0.4437***	−0.0542	−0.0763**	−0.0282	−0.0188
	(0.1141)	(0.0826)	(0.0702)	(0.0717)	(0.0434)	(0.0312)	(0.0263)	(0.0269)
Agric. technology assets	0.4811***	0.5739***	0.5355***	0.4475***	0.0102	−0.0140	−0.0263	−0.0393**
	(0.1569)	(0.1115)	(0.0848)	(0.0736)	(0.0737)	(0.0258)	(0.0202)	(0.0163)
Agric. non-technology assets	0.0399***	0.0314***	0.0277***	0.0268***	0.0074***	0.0077***	0.0065***	0.0062***
	(0.0085)	(0.0075)	(0.0065)	(0.0080)	(0.0028)	(0.0019)	(0.0019)	(0.0017)
Adoption of MVs	−0.0902	−0.1306**	−0.1547***	−0.0834	0.0840*	0.0632**	0.0477***	0.0474**
	(0.1537)	(0.0625)	(0.0585)	(0.0865)	(0.0495)	(0.0251)	(0.0182)	(0.0205)
Rainfed cult. land × Adoption of MVs	0.0088	0.0138***	0.0055*	0.0020	−0.0044	−0.0063	−0.0054***	−0.0063***
	(0.0337)	(0.0050)	(0.0031)	(0.0031)	(0.0121)	(0.0049)	(0.0017)	(0.0011)
Ave. distance to bank	−0.0003	0.0002	0.0004	0.0001	−0.0003	−0.0009***	−0.0011***	−0.0014***
	(0.0010)	(0.0008)	(0.0007)	(0.0007)	(0.0004)	(0.0003)	(0.0002)	(0.0002)
ICT technologies	0.0650***	0.0898***	0.0749***	0.0701***	0.0137**	0.0083	0.0026	−0.0030
	(0.0217)	(0.0164)	(0.0163)	(0.0213)	(0.0068)	(0.0059)	(0.0052)	(0.0061)
Transportation means	0.0156	0.0136	0.0321***	0.0407***	−0.0019	0.0038	0.0086**	0.0122***
	(0.0127)	(0.0102)	(0.0093)	(0.0088)	(0.0050)	(0.0040)	(0.0040)	(0.0040)
Year dummy 2014	−0.9882***	−0.7979***	−0.6685***	−0.3879***	−0.5159***	−0.5324***	−0.4812***	−0.4425***
	(0.0880)	(0.0651)	(0.0643)	(0.0820)	(0.0398)	(0.0259)	(0.0236)	(0.0216)
Constant	4.8767***	5.6492***	6.2569***	6.8764***	7.8294***	8.2300***	8.3908***	8.5448***
	(0.1863)	(0.1498)	(0.1198)	(0.1630)	(0.0682)	(0.0511)	(0.0385)	(0.0370)
N	3344				3344			

Notes: standard errors clustered at EA level in parentheses. Significance level $^{*}p < 0.1$, $^{**}p < 0.05$, $^{***}p < 0.01$.

Table 6
Welfare effects of diversification (Shannon index)

	Income quantiles				DES quantiles			
	0.20	0.40	0.60	0.80	0.20	0.40	0.60	0.80
Crop divers.	0.2369***	0.1234***	0.1248***	0.0885**	0.0604***	0.0361***	0.0384***	0.0249**
	(0.0707)	(0.0358)	(0.0334)	(0.0436)	(0.0146)	(0.0124)	(0.0102)	(0.0099)
Labor divers.	0.7301***	0.5848***	0.4800***	0.4601***	0.0798*	0.0251	0.0302	0.0422
	(0.1010)	(0.0761)	(0.0783)	(0.0794)	(0.0453)	(0.0280)	(0.0246)	(0.0270)
Crop divers. (residuals)	−0.0236	0.0108	0.0088	−0.0042	−0.0151	−0.0064	−0.0152**	−0.0118
	(0.0312)	(0.0138)	(0.0178)	(0.0226)	(0.0101)	(0.0063)	(0.0062)	(0.0158)
Labor divers. (residuals)	−0.1581***	−0.1498**	−0.1174	−0.0531	−0.0296	−0.0014	0.0071	0.0067
	(0.0547)	(0.0700)	(0.0788)	(0.0938)	(0.0349)	(0.0303)	(0.0208)	(0.0243)
Rainfed cultivated land	0.0050	0.0034	0.0020	0.0000	0.0009	0.0019**	0.0015	0.0011
	(0.0042)	(0.0040)	(0.0015)	(0.0096)	(0.0011)	(0.0009)	(0.0012)	(0.0010)
TLU	0.0783***	0.0722***	0.0698***	0.0821***	0.0058*	0.0026	0.0065	0.0139***
	(0.0277)	(0.0172)	(0.0146)	(0.0151)	(0.0031)	(0.0044)	(0.0077)	(0.0034)
Age of HH head	0.0016	0.0021	−0.0021	−0.0037**	0.0007	0.0004	0.0002	0.0010*
	(0.0023)	(0.0015)	(0.0015)	(0.0016)	(0.0009)	(0.0006)	(0.0004)	(0.0005)
HH size	0.0173	0.0233***	0.0267***	0.0171*	−0.0802***	−0.0912***	−0.0939***	−0.0965***
	(0.0113)	(0.0073)	(0.0068)	(0.0095)	(0.0056)	(0.0031)	(0.0024)	(0.0028)
Ave. HH edu. years	0.0107	0.0085*	−0.0000	0.0140*	0.0028	0.0013	0.0001	0.0027
	(0.0068)	(0.0048)	(0.0052)	(0.0073)	(0.0025)	(0.0017)	(0.0015)	(0.0019)
HH with female head	−0.2156**	−0.3274***	−0.3666***	−0.3800***	−0.0537	−0.0807***	−0.0294	−0.0235
	(0.1036)	(0.0746)	(0.0885)	(0.0753)	(0.0438)	(0.0303)	(0.0274)	(0.0233)
Agric. technology assets	0.3173***	0.4293***	0.4632***	0.3904***	−0.0031	−0.0096	−0.0339	−0.0454**
	(0.1041)	(0.1172)	(0.1336)	(0.0766)	(0.0327)	(0.0246)	(0.0213)	(0.0182)
Agric. non-technology assets	0.0433***	0.0370***	0.0348***	0.0307***	0.0066**	0.0074***	0.0066***	0.0048***
	(0.0095)	(0.0060)	(0.0056)	(0.0071)	(0.0030)	(0.0019)	(0.0017)	(0.0017)
Adoption of MVs	−0.1107	−0.1389**	−0.1384**	−0.1466	0.0807**	0.0650**	0.0488***	0.0544**
	(0.1796)	(0.0595)	(0.0630)	(0.0965)	(0.0371)	(0.0258)	(0.0173)	(0.0213)
Rainfed cult. land × Adoption of MVs	−0.0058	0.0097**	0.0055*	0.0010	−0.0038	−0.0057	−0.0051***	−0.0066***
	(0.0346)	(0.0048)	(0.0028)	(0.0096)	(0.0073)	(0.0052)	(0.0015)	(0.0011)
Ave. distance to bank	−0.0009	−0.0004	0.0002	−0.0001	−0.0003	−0.0009***	−0.0010***	−0.0012***
	(0.0010)	(0.0009)	(0.0008)	(0.0006)	(0.0003)	(0.0003)	(0.0002)	(0.0003)
ICT technologies	0.0830***	0.0925***	0.0692***	0.0516**	0.0174**	0.0092	0.0011	−0.0024
	(0.0214)	(0.0160)	(0.0166)	(0.0208)	(0.0076)	(0.0064)	(0.0053)	(0.0057)
Transportation means	0.0103	0.0093	0.0268***	0.0427***	−0.0012	0.0038	0.0100***	0.0122***
	(0.0111)	(0.0093)	(0.0092)	(0.0110)	(0.0066)	(0.0042)	(0.0037)	(0.0040)
Yea dummy 2014	−1.0431***	−0.7911***	−0.6332***	−0.3640***	−0.5516***	−0.5503***	−0.4889***	−0.4438***
	(0.1435)	(0.0751)	(0.0757)	(0.0834)	(0.0412)	(0.0291)	(0.0239)	(0.0244)
Constant	4.2213***	5.0943***	5.7825***	6.4502***	7.7433***	8.2020***	8.3495***	8.5028***
	(0.2203)	(0.1283)	(0.1458)	(0.1920)	(0.0733)	(0.0557)	(0.0412)	(0.0419)
N	3344				3344			

Notes: Standard errors clustered at EA level, in parentheses. Significance level: $^{*}p < 0.1$, $^{**}p < 0.05$, $^{***}p < 0.01$.

Table 7
Welfare effects of diversification (Berger-Parker index)

	Income quantiles				DES quantiles			
	0.20	0.40	0.60	0.80	0.20	0.40	0.60	0.80
Crop divers.	0.1493***	0.0980***	0.1032***	0.0596*	0.0504***	0.0366***	0.0347***	0.0263***
	(0.0455)	(0.0312)	(0.0270)	(0.0321)	(0.0160)	(0.0109)	(0.0086)	(0.0097)
Labor divers.	0.9985***	0.8293***	0.7504***	0.7109***	0.1103	0.0181	0.0485	0.0409
	(0.1453)	(0.1204)	(0.1277)	(0.1342)	(0.0739)	(0.0501)	(0.0403)	(0.0406)
Crop divers. (residuals)	−0.0471**	−0.0126	−0.0016	−0.0242	−0.0116	−0.0108	−0.0116**	−0.0134**
	(0.0234)	(0.0187)	(0.0115)	(0.0150)	(0.0101)	(0.0075)	(0.0047)	(0.0057)
Labor divers. (residuals)	−0.3027**	−0.3194***	−0.3629***	−0.2738**	−0.0667	−0.0055	0.0135	0.0262
	(0.1209)	(0.1237)	(0.1170)	(0.1315)	(0.0996)	(0.0424)	(0.0508)	(0.0440)
Rainfed cultivated land	0.0046	0.0038	0.0020	−0.0003	0.0009	0.0019**	0.0017	0.0012
	(0.0042)	(0.0040)	(0.0015)	(0.0091)	(0.0011)	(0.0009)	(0.0012)	(0.0009)
TLU	0.0749***	0.0688***	0.0715***	0.0775***	0.0057**	0.0022	0.0071	0.0143***
	(0.0258)	(0.0117)	(0.0150)	(0.0161)	(0.0025)	(0.0048)	(0.0077)	(0.0033)
Age of HH head	0.0029	0.0019	−0.0022	−0.0040**	0.0008	0.0006	0.0003	0.0011**
	(0.0022)	(0.0014)	(0.0014)	(0.0015)	(0.0009)	(0.0006)	(0.0004)	(0.0005)
HH size	0.0205*	0.0277***	0.0319***	0.0195**	−0.0781***	−0.0902***	−0.0933***	−0.0958***
	(0.0107)	(0.0066)	(0.0071)	(0.0088)	(0.0053)	(0.0030)	(0.0024)	(0.0026)
Ave. HH edu. years	0.0115*	0.0083*	−0.0010	0.0133*	0.0026	0.0008	0.0005	0.0026
	(0.0068)	(0.0049)	(0.0052)	(0.0075)	(0.0026)	(0.0017)	(0.0015)	(0.0018)
HH with female head	−0.2313***	−0.3573***	−0.3830***	−0.3598***	−0.0606	−0.0721**	−0.0309	−0.0199
	(0.0862)	(0.0671)	(0.0762)	(0.0755)	(0.0427)	(0.0318)	(0.0279)	(0.0242)
Agric. technology assets	0.3524***	0.4579***	0.4979***	0.4113***	−0.0031	−0.0152	−0.0372	−0.0450***
	(0.1221)	(0.0958)	(0.1097)	(0.0988)	(0.0341)	(0.0252)	(0.0228)	(0.0166)

(*continued on next page*)

Table 7 (*continued*)

	Income quantiles				DES quantiles			
	0.20	0.40	0.60	0.80	0.20	0.40	0.60	0.80
Agric. non-technology assets	0.0453***	0.0398***	0.0365***	0.0278***	0.0070**	0.0073***	0.0059***	0.0053***
	(0.0099)	(0.0058)	(0.0061)	(0.0066)	(0.0031)	(0.0020)	(0.0016)	(0.0017)
Adoption of MVs	−0.1596	−0.1134*	−0.1717***	−0.1543*	0.0674	0.0745***	0.0406**	0.0503**
	(0.1674)	(0.0584)	(0.0560)	(0.0922)	(0.0433)	(0.0259)	(0.0176)	(0.0207)
Rainfed cult. land × Adoption of MVs	0.0023	0.0079*	0.0049*	0.0008	−0.0024	−0.0074	−0.0053***	−0.0067***
	(0.0310)	(0.0048)	(0.0029)	(0.0090)	(0.0083)	(0.0053)	(0.0015)	(0.0010)
Ave. distance to bank	−0.0010	−0.0001	−0.0001	−0.0003	−0.0004	−0.0009***	−0.0010***	−0.0012***
	(0.0011)	(0.0007)	(0.0009)	(0.0006)	(0.0004)	(0.0003)	(0.0002)	(0.0003)
ICT technologies	0.0758***	0.0915***	0.0713***	0.0618***	0.0181**	0.0120*	0.0029	−0.0024
	(0.0195)	(0.0152)	(0.0157)	(0.0182)	(0.0072)	(0.0062)	(0.0054)	(0.0056)
Transportation means	0.0122	0.0119	0.0291***	0.0444***	−0.0019	0.0032	0.0077**	0.0123***
	(0.0112)	(0.0090)	(0.0097)	(0.0094)	(0.0062)	(0.0042)	(0.0038)	(0.0041)
Year dummy 2014	−0.8988***	−0.7129***	−0.5585***	−0.3414***	−0.5144***	−0.5367***	−0.4724***	−0.4323***
	(0.0980)	(0.0636)	(0.0653)	(0.0822)	(0.0390)	(0.0261)	(0.0228)	(0.0222)
Constant	4.0507***	4.8334***	5.5090***	6.3028***	7.7018***	8.1923***	8.3287***	8.4794***
	(0.2280)	(0.1654)	(0.1752)	(0.2063)	(0.0957)	(0.0642)	(0.0507)	(0.0515)
N	3344				3344			

Notes: standard errors clustered at EA level in parentheses. Significance level: *$p < 0.1$, **$p < 0.05$, ***$p < 0.01$

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